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VISUAL PERFORMANCE ON THE MOON

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Introduction

This paper will deal with the properties of the lunar optical and visual environment as they may influence man's ability to function on the moon's surface. As more and better quantitative data are gathered from the Luna, Ranger, and Surveyor programs we are increasingly able to estimate illumination, brightness and contrast levels which will confront those lunar explorers and working scientists whose visual performance will be of great importance to the success of the venture. These new data also enable us to design specific laboratory and field experiments to evaluate the effects of lunar environmental factors upon human vision, and may lead to special operational techniques or optical aids to enhance the safety and productivity of the mission. I will limit my remarks to phenomena related to the visible part of the electromagnetic spectrum (380-750 nanometers), assuming that adequate protection from stressful amounts of other wavelengths is provided. We will begin with a review of the physical properties of the lunar visual environment as we now believe them to be, and will show how human performance may be affected. Some of the ongoing research which is addressed to specific problem areas will be described, together with some suggestions for other studies which need to be done. Finally, there will be a few comments on the selection and training of personnel for the lunar missions and some possible experimental studies in human vision will be suggested which could be made in parallel with other behavioral investigations in the Lunar International Laboratory.

The Lunar Visual Environment

The natural illumination of the lunar surface comes from direct sunlight, reflected sunlight (primarily from Earth, but in some small degree from other planets in the solar system), and from starlight. During lunar day about 13,000 ft-C are incident on the surface, so that the brighter portions of the scene may have an apparent luminance in excess of 1000 ft-L. Owing to the lack of atmospheric scattering, it may be expected that the deepest shadows will approach effectively zero luminance (10^{-6} ft-L or less). Without sun, illumination levels are likely to be in the neighborhood of 10 ft-C for full Earth conditions, with a resulting maximum luminance of something over 1 ft-L, but decreasing markedly with Earth phase angle. Starshine alone is estimated to produce about 3×10^{-5} ft-C, and, unlike Earth and Sun, of a diffuse rather than uni-directional nature, so that a general average luminance might approach 10^{-5} ft-L, without the severe shadow casting effects just noted. These numbers are only approximations, and are intended merely to indicate the wide range of luminances and contrasts which inhere in the lunar scene. They give us an opportunity to estimate the adaptation of the observer, and hence to say something about his performance capabilities, at least for simple discriminatory tasks. The case of elementary detection of luminance contrast has been extensively studied by Blackwell (1946[1]) and others, and Figure 1 shows the manner in which contrast and size of objects are related at a wide range

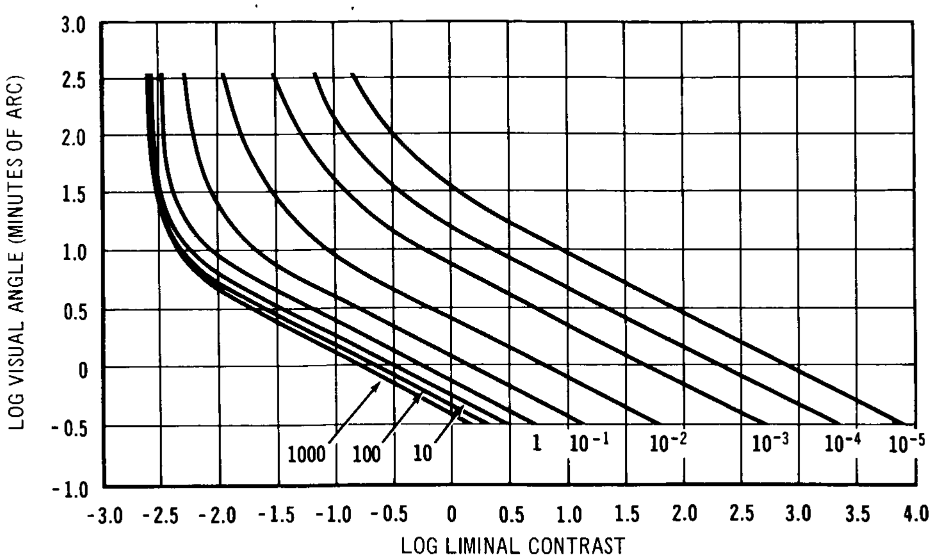

Fig. 1. Threshold contrast as a function of stimulus size for various levels of adapting field luminance. (After Blackwell)

of adapting luminances. The near coincidence of the curves at 1000, 100, and 10-ft-L for objects subtending 10 minutes or more is important to note, for it indicates that eye-protective filters which transmit 10 per cent or one per cent of visible light will not significantly impair contrast discrimination at the higher ambient levels of field luminance. Performance at 1 ft-L and at 10^{-5} ft-L are also shown in this Figure. It is clear that the expected luminance levels on the lunar surface are, in the main, well within the operational tolerances of ordinary seeing. There are, however, certain special properties of the lunar visual environment which are unlike any naturally-occurring terrestrial ones, and it is these uniquely lunar conditions which are of greatest interest to us.

The lack of a lunar atmosphere has several important consequences for the lunar explorer and scientist. We are accustomed, in the terrestrial environment, to natural illumination which results from direct sunlight plus a significant amount of diffuse light due to molecular and particulate scattering by our atmosphere. This scattered light, combining with reflected light from nearby objects, serves to illuminate those parts of the scene which are shaded from the direct rays from the sun and therefore to reduce the range of luminances in our field of view. The first consequence of a missing atmosphere, then, is that shadowed parts of the moon's surface will be very black; the contrasts in the scene will be extremely high and it seems likely that details of the shadowed areas can only be seen by use of some reflective device or auxiliary light source. Another property of our atmosphere, generally known as atmospheric haze, we habitually use in the estimation of distance and size of features. Since this cue will not be available, and because objects of familiar size may not be available for direct visual comparison, it is believed that the judgment of size and distance will have to be aided by special devices (theodolites, rangefinders) and by special observing techniques (motion parallax), at least at distances where man's accommodation and convergence cues are inoperative and stereopsis no longer helps. Since the sky above the horizon will appear essentially black (unless the Sun or Earth is in the field of view; see below), it may happen that the adaptive state of the man on the lunar surface will be highly variable, and his visual performance under such conditions cannot confidently be predicted from existing data. Finally, for the sunlit and earthlit conditions, the highly directional nature of the illumination will, especially at low angles, combine with the low average surface reflectance to produce wide extremes in the appearance of the terrain. Some idea of this can be gained from Figure 2, in which we have photographed a small area of simulated moon surface (Average $r = 0.15$). The difference between the upper and lower photograph, which

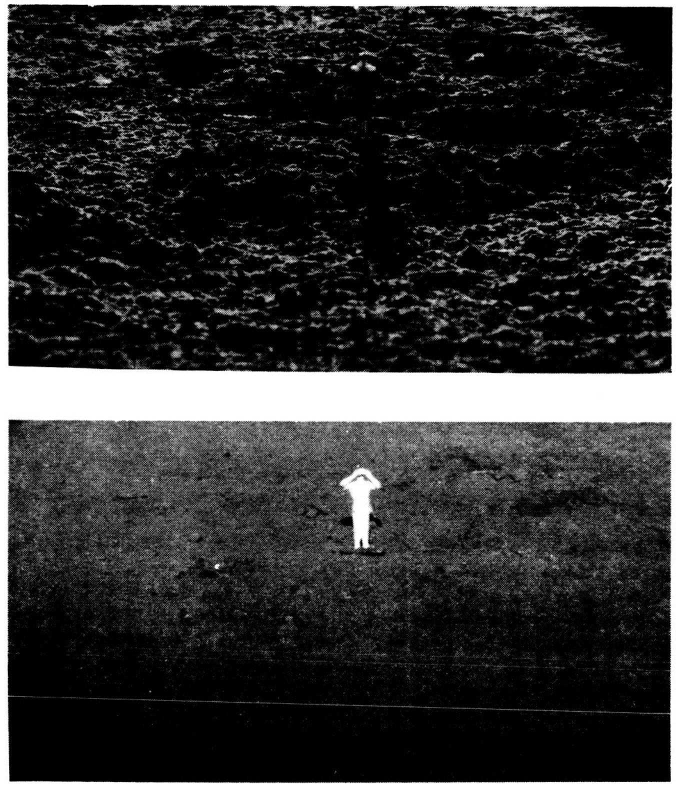

Fig. 2. Photograph of a lunar surface model of average reflectance 0.15, showing differences in appearance with sun's azimuth. Upper and lower exposures identical; camera and model positions same.

were identically exposed and processed, are due solely to a change in the sun's azimuth, with elevation held constant. It is clear that a man walking on the lunar surface is confronted by quite a different scene in the two instances. Because visual cues are essential to the act of walking under conditions of 1/6 g. we must be sure that he is able to use these cues without errors of judgment. It may be that an operational strategy for getting about should be devised in order to optimize the man's performance and reduce the possibility of a costly or hazardous accident.

Up to this point we have not considered one aspect of the lunar environment which may be of extreme importance to man's visual performance. This, of course, is the presence of the sun itself in the otherwise dark sky of lunar day. With an apparent luminance of around 6.4×10^8 ft-L, and subtending a half degree, the sun constitutes a glare source of tremendous magnitude.

If the man on the lunar surface must operate with the solar disc in his visual field, it is imperative that suitable protective devices be provided which will prevent discomfort or temporary or permanent visual disability. It has been argued that the man will always operate so as to avoid looking into or near the sun, but we must recognize the probability that accidental exposure will occur. Furthermore, the eye-protective devices which have been proposed are far from ideal from the visual standpoint, tending to introduce contrast and acuity losses by reason of scattering or distortion. Other potentially serious glare sources may be introduced by man himself. The need for thermal regulation of lunar excursion vehicles and, eventually, fixed habitats, has dictated that their surfaces be so treated as to be highly reflective. These surfaces are likely, therefore, to be very much brighter than the surrounding scene, especially if seen partly or wholly against the dark sky. As an extreme example, we may take the case of the highly polished aluminum surface which has been proposed for the Lunar Excursion Module. Figure 3

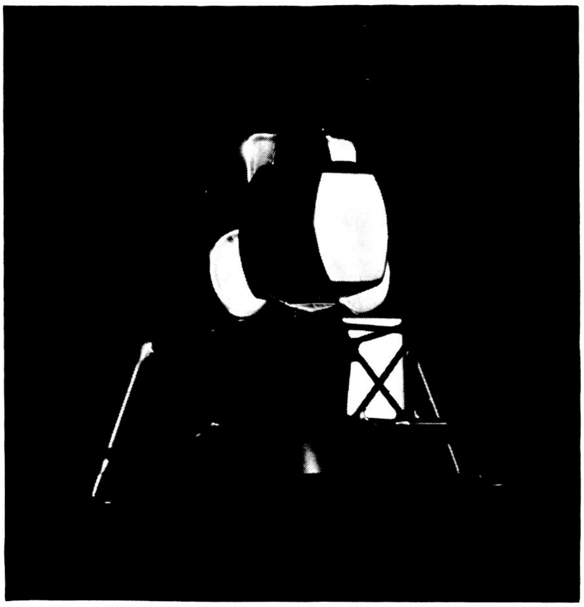

Fig. 3. Photograph of LEM model with ascent stage of polished aluminum and descent stage anodized. Sun at 14° elevation.

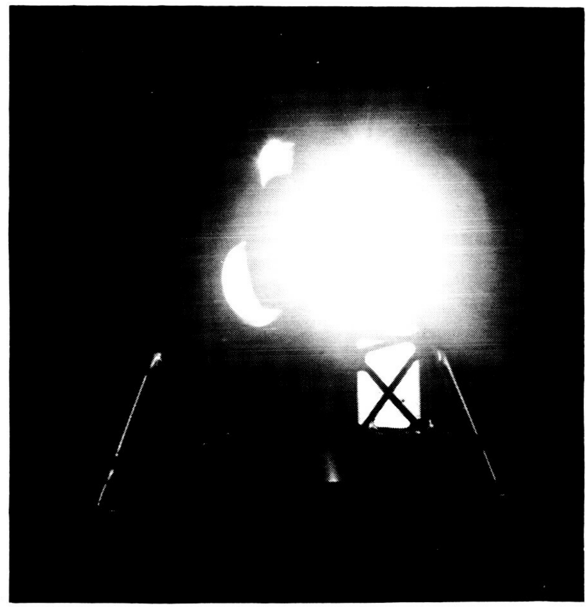

Fig. 4. Photograph of LEM model, as in Figure 3, but rotated to show intense glare from reflected image of the sun.

shows a model of the LEM in which the surfaces of the ascent stage are of mirror-like aluminum and those of the descent stage of somewhat more diffusely reflecting anodized aluminum. From the vantage point of the photograph no serious visual problem may exist, but if the camera is moved only a degree or two, as is shown in Figure 4, an intensely bright and angularly large glare pattern is suddenly seen. Since, for a plane surface, the apparent luminance of this reflection is about 5.8×10^9 ft-L (90 per cent of that of the sun) and of the same angular extent as the sun itself, it is clear that the problem is severe, especially because of the element of surprise which makes any voluntary protective maneuver relatively ineffectual. The result of accidentally encountering such a beam of reflected light could be a temporary loss of visual sensitivity in the extreme case, and impairment of performance in less extreme instances.

Some Problems for Research

Although many facets of human visual performance have been systematically and quantitatively studied over the past century, these have largely been concerned with somewhat abstracted and highly artificial conditions. While we are able to make quite precise predictions of visual capabilities in simple situations and for simple sorts of discriminations, our predictive tools are frequently inadequate for the solution of operational problems. For this reason it is often necessary to resort to applied research methods, simulations, and field tests rather than to await the eventual appearance of appropriate data from comprehensive basic studies. The research program of the Visibility Laboratory includes both basic and applied studies of visual performance under sponsorship of the National Aeronautics and Space Administration. We are performing experiments which will provide, for the first time, precise and systematic data regarding vision in the peripheral field at a wide range of adaptation levels, exposure times, and stimulus sizes; this is only one example of a long-term data acquisition program. At an intermediate level, we are examining the effects on vision of a bright surround – a problem suggested by the problem of seeing into lunar shadows or into recesses on the exterior of a space vehicle. And we have conducted studies during GEMINI flights 5 and 7 to discover whether prolonged exposure to the spacecraft environment would affect performance on a kind of visual acuity task.[2]

Meanwhile, knowledge of the photometric properties of the moon are becoming better known. The recent results of the Surveyor program, especially from the analyses of luminances and color but also of textural features of the surface, give us some notion of the visual situation for one (rather dark) area. The Astrogeology Branch of the USGS and the Jet Propulsion Laboratory are, at this writing, engaged in reducing data from Surveyor I's photometric system. Some preliminary results by Rennilson[3] which indicate the agreement between the data of Fedoretz and the Surveyor measurements are shown in Figure 5.

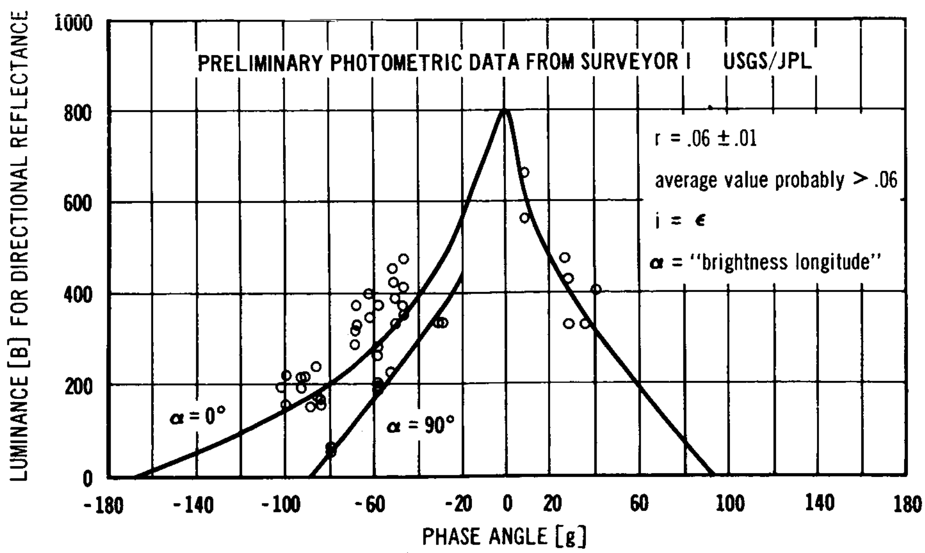

Fig. 5. Preliminary data (open circles) from Surveyor I compared with the lunar photometric model of Fedoretz.

There are many aspects of visual behavior which can be studied in terrestrial laboratories and the data applied to the lunar problem. It is to be hoped that scientists of many nations will become interested in one or another phase of visual performance so that we will be able to assess the effects as such things as highly intense glare, rapidly changing adaptation, special gas mixtures, reduced gravity over long periods, distortions and higher-order phenomena resulting from confinement and the like. Only then can we take full advantage of the man's ability to use his eyes for scientific work on the lunar surface, while insuring his visual safety and the value of his observations.

Selection and Training of Personnel

From a purely visual standpoint, it is desirable that due consideration be given to the capacity of the individual for operating efficiently in the LIL environment. It is obvious that he should have very good visual acuity and be free from any ocular pathology, and he should be capable of better than average accommodation and convergence. Perhaps less obviously, he should be young, for the effects of glare due to intra-ocular scattering become more severe with age. His training should include sufficient time with simulators so that he will learn new skills in judging the features in his unfamiliar optical environment, and in optimizing his own safety and productivity during his mission. He must be taught to use his peripheral retina for operation during periods of darkness, and he should learn the best techniques for search and scanning. Importantly, he must be made alert to the dangers of debilitating amounts of glare and instructed how to avoid it. For the fine discrimination of hue differences, he should have some knowledge of how best to make his observations. This list could be greatly lengthened, but the point to be made is that selection should include tests not ordinarily performed by the practicing ophthalmologist, and that special training should be provided in advance of the mission.

Vision Research on the Moon

I believe that there are certain studies of human vision which are important to our overall space program, but which are difficult or impossible to perform on the surface of the earth. For these, it would be desirable to incorporate in the LIL schedule time for some visual experiments. With a relatively minor cost in weight, time, or funds, it appears feasible to conduct these investigations as a part of the LIL program.

One example is the study of the effects of long term existence under reduced gravity. While we have already made a beginning on this problem in the GEMINI program, the data are limited to a single visual discrimination task, very few observations, and an experimental population of only four individuals. On the moon, a wide range of visual discriminations could be examined over considerable periods of time.

Another unique research possibility concerns the study of highly intense glare effects, to which I have already alluded. Earthbound data are relevant only to the case of relatively low glare intensities and to a few kinds of visual tasks. With an unvarying sun available, controlled experiments will be possible.

Finally, in the absence of an atmosphere, certain studies will be possible during the lunar night which are impossible on Earth. These include the detection and identification of dim-light phenomena, vision in the peripheral field, and visual performance capability under these special conditions.

Conclusion

Our experience in space thus far has generally affirmed the notion that human vision is a uniquely valuable asset in space operations. In order that we take full advantage of man's visual capabilities, we must study his potential for operating under the unique environmental conditions anticipated for all phases of space exploration. While we must safeguard his vision, we should, at the same time, provide ample opportunity for him to utilize his visual skills. It is of the greatest importance that visual conditions be kept in the forefront of our attention as we plan future missions; that competent visual scientists be consulted whenever an item of equipment or operational plan is considered. But it is also the responsibility of these scientists to provide their best estimates of the capabilities and limitations of the human visual process. In this endeavor we must look for and encourage the contribution of ideas and scientific data from all countries.

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This paper discusses the optical and photometric properties of the lunar surface environment and their implications for human visual performance. The need for specialized training of selenonauts is pointed out, and some suggested studies for the Lunar International Laboratory are given.

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